Hilbert-Huang Transform:

A method for analyzing nonlinear and nonstationary data

presented by:

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N A S A   M e d i c a l   T e c h n o l o g y   S u m m i t

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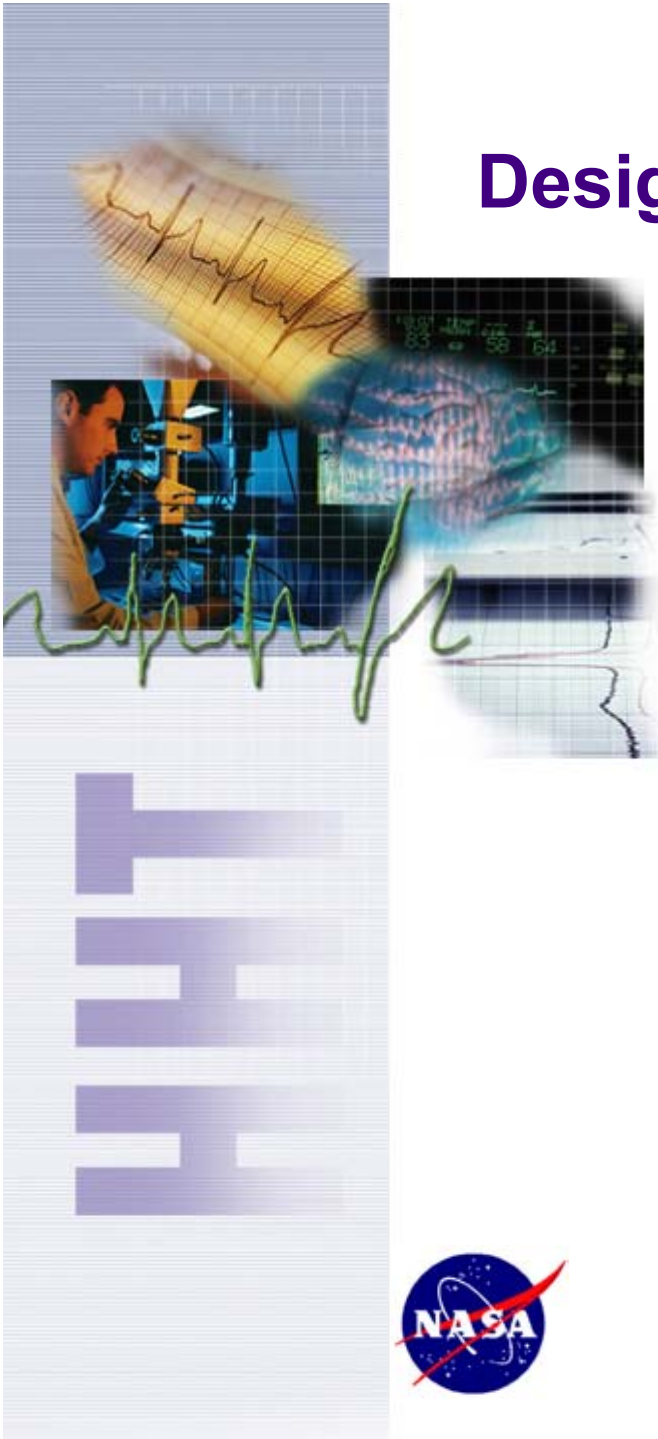
Presentation Outline

- Design motivation and concept inception
- Technology description
- Market potential
- Status of development
- Technology details and results
- Summary
- Contact info
- Acknowledgements
- Q&A

Design Motivation & Concept Inception

Problems result from characteristics of data:

- **Insufficient sample size**

- **Nonstationary data**

- **Nonlinear data**

Design Motivation & Concept Inception

Prior art:

- Wavelet analysis, Wigner-Ville transforms, Fourier analysis

- Singular spectral analysis, nonlinear phase plane analysis

Each has limitations

Result is inaccurate interpretation of underlying physics

Design Motivation & Concept Inception

The basic problem in analyzing data:

- All existing methods are for either *linear* or *stationary* data or they assume *deterministic processes.*

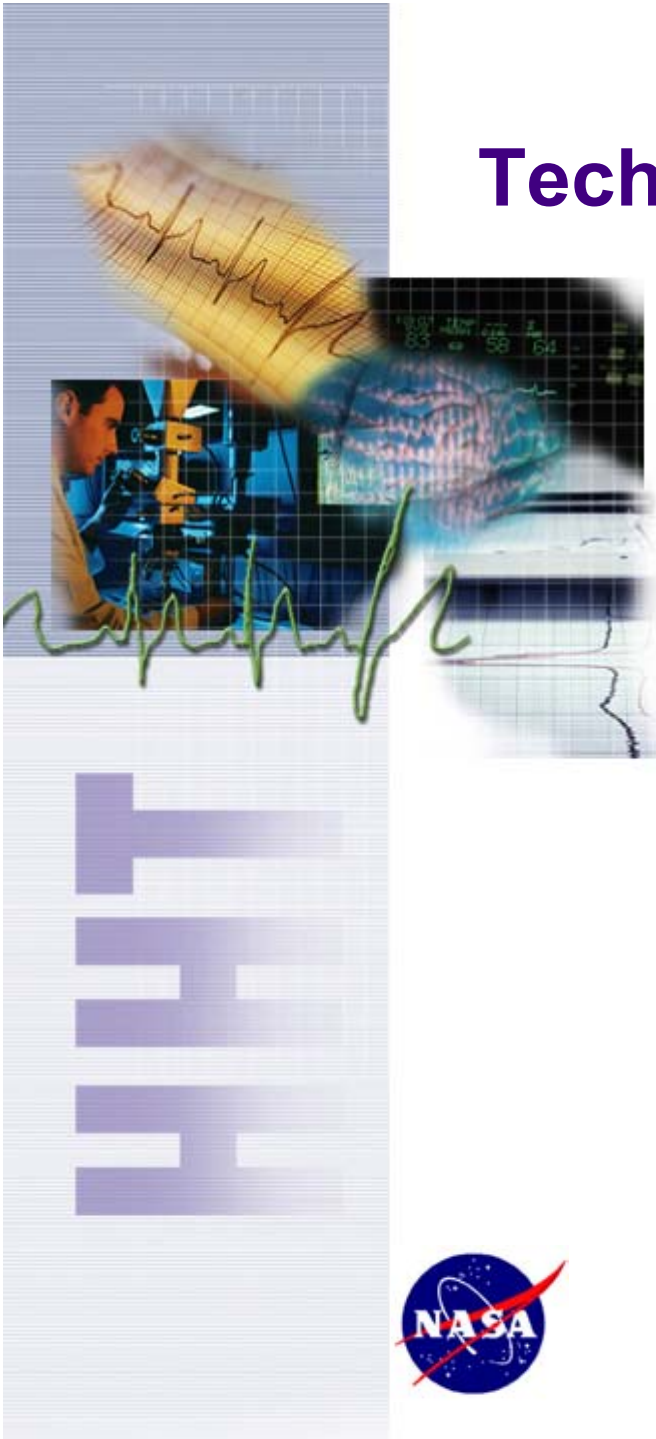- Most actual data are *nonlinear, nonstationary,* and *stochastic*.
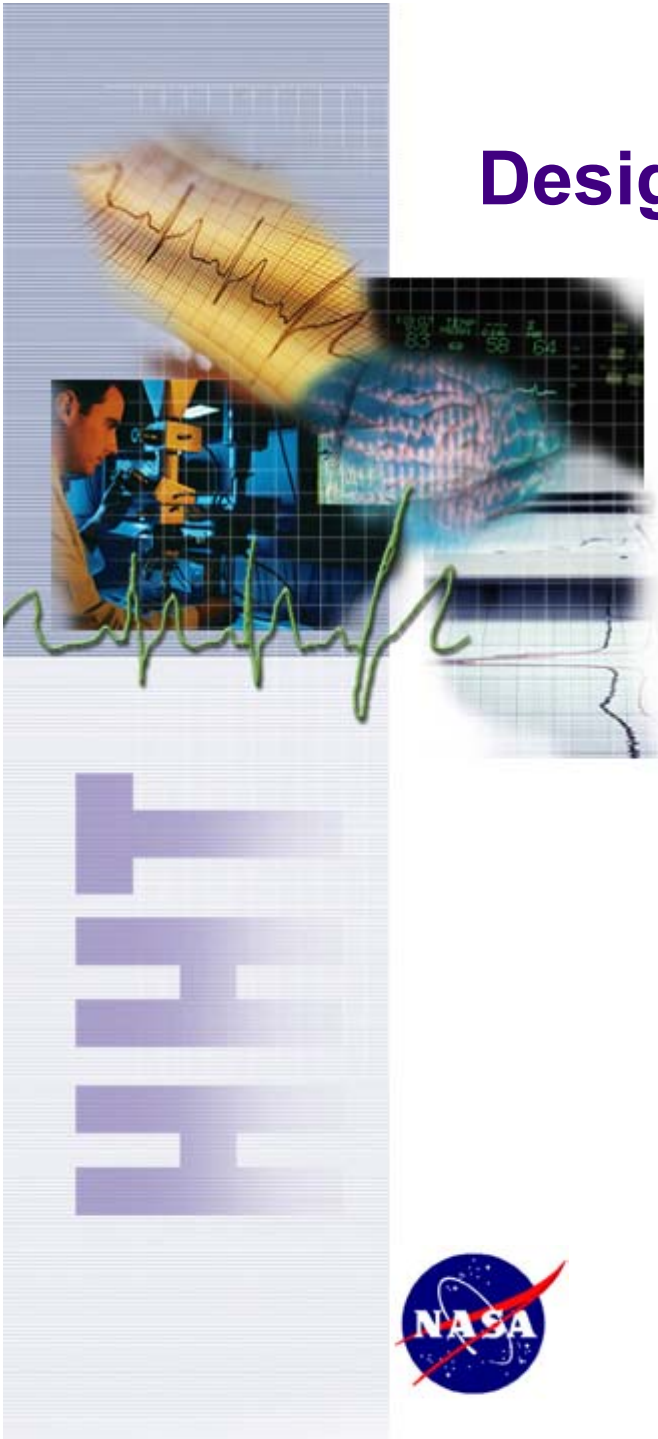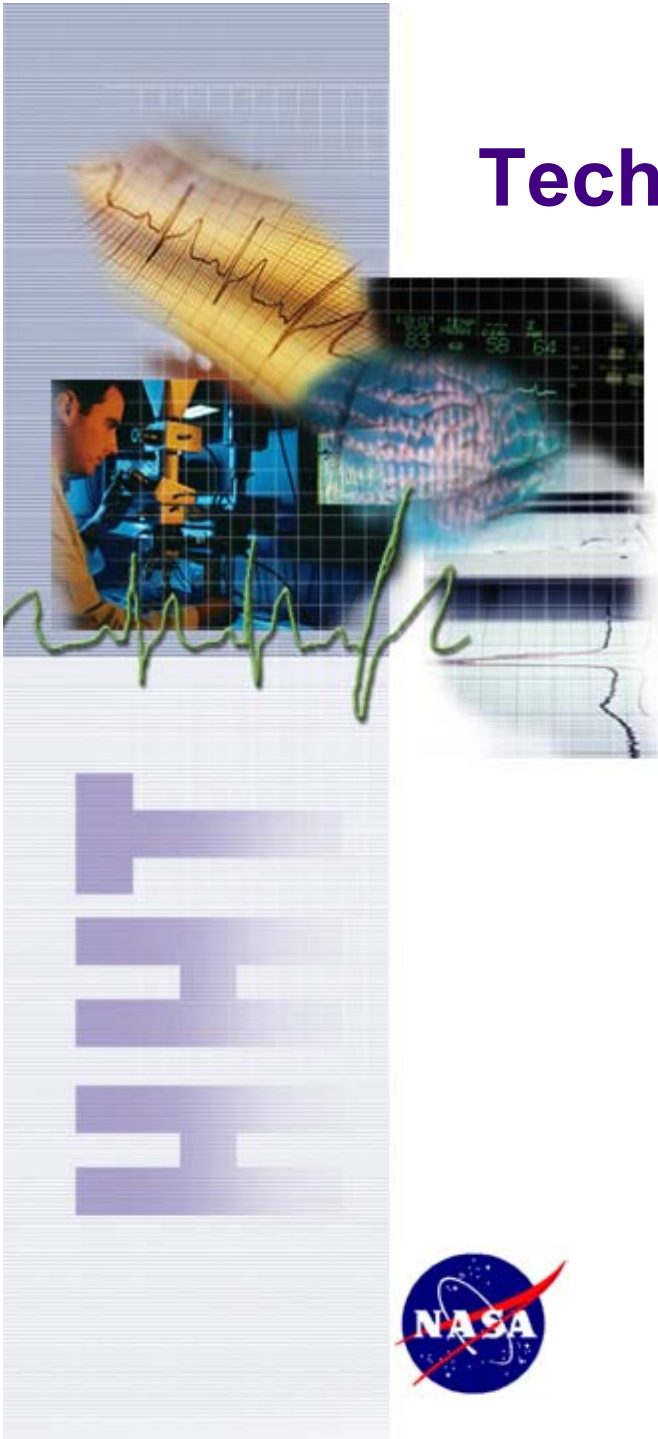
Technology Description

Goal:

- **Develop a means of accurately analyzing nonlinear, nonstationary data**

Technology Description

Basic concept:

- Any applied mathematics method that analyzes nonlinear, nonstationary data has to be adaptive.

- To be effective and rich in information, any basis has to involve a finite and often small number of discrete *modes* that retain the intrinsic properties of the original data.

Technology Description

Technical goals of data analysis:

- **To define local time scale or frequency**

- **To define local energy density**

- **To define joint frequency-energy distribution**
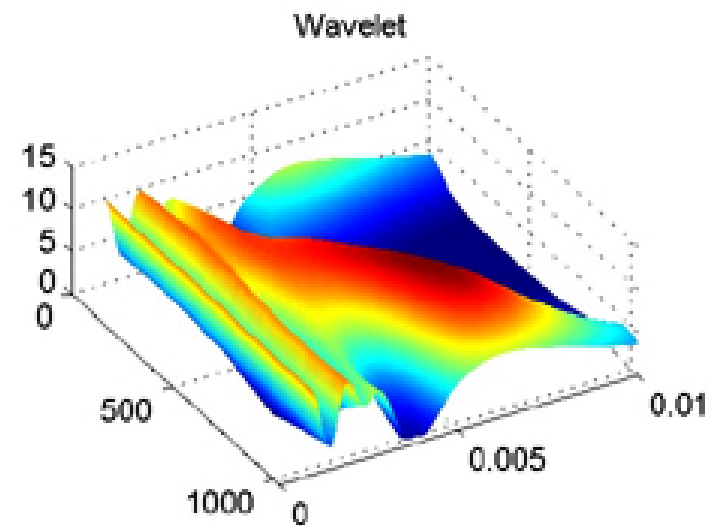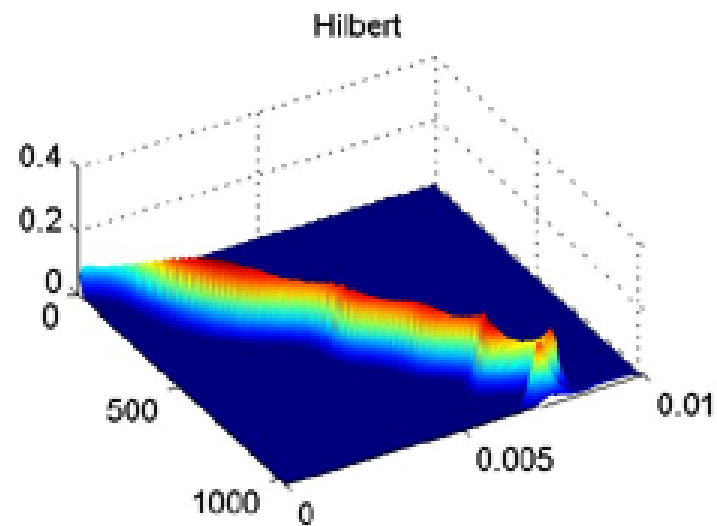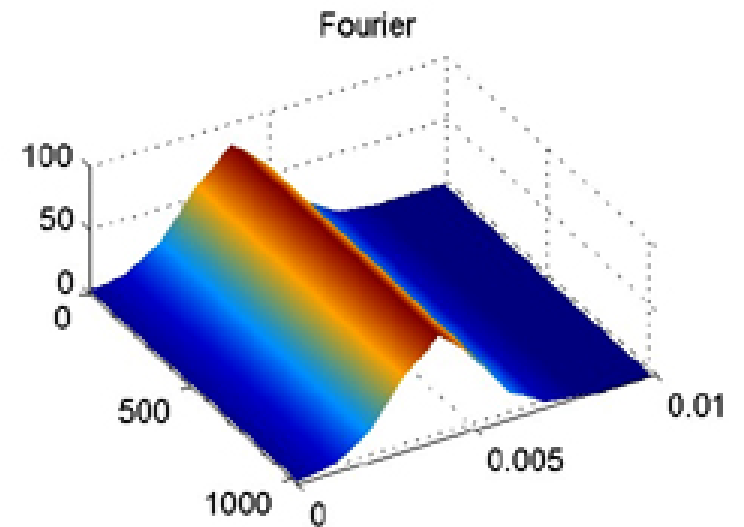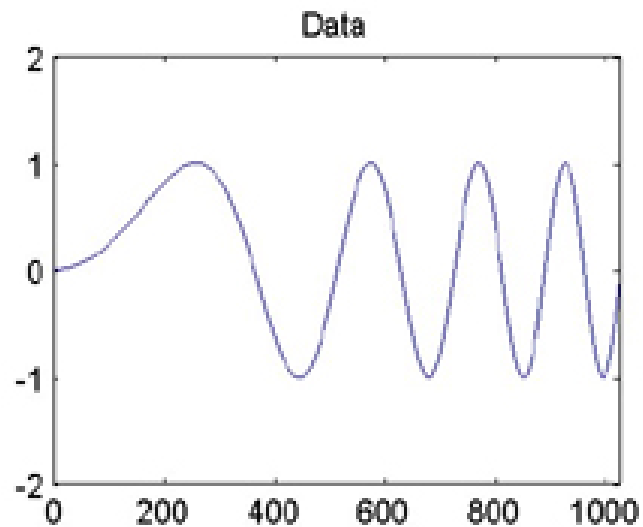
Technology Description

Method:

- **Empirical Mode Decomposition method extracts intrinsic mode functions (IMFs), (i.e., oscillation modes within data) which still retain intrinsic characteristics of the data**

- **Hilbert-Huang Transform (HHT) converts IMFs into local energy and instantaneous frequencies as a base for the full energy-frequency-time distribution of data (i.e., Hilbert spectrum)**

- **Physical signal is filtered by reconstructing signal from selected IMFs or IMF sections**

Comparisons: Fourier, Hilbert & Wavelet

Technology Description

Results:

- An adaptive basis to filter signal

- Frequency defined as a function of time by differentiation rather than convolution analysis

- Sharp identification of embedded structures

- A more simple and revealing interpretation than prior methods

Key Considerations

- **Conceptually simple and direct**

- **An efficient, adaptive, user-friendly set of algorithms**

- **Capable of analyzing nonlinear and nonstationary signals as well as linear and stationary signals**

Key Considerations

- **Improves accuracy by using an adaptive basis to preserve intrinsic properties of data**

- **Yields results with more physical meaning and a different perspective than existing tools**

- **Useful in analyzing a variety of physiological signals as well as many other signals from nonlinear and nonstationary processes**

Benefits

Precision:

- **More precise time-frequency representation of signal data than with "Fourier-type" methods**

- **Sharper filter performance than provided by "Fourier-type" methods**

Benefits

Flexibility:

- **Designed for processing nonlinear and nonstationary signals**

- **Flexible enough to analyze any data (linear or nonlinear) and stationary or nonstationary signals**

Benefits

Accuracy:

- **Preserves intrinsic properties of data**

- **Offers a microscopic view of data not limited by the uncertainty principle**

- **Does not impose *a priori* assumptions on data, as in Fourier methods (i.e., that assume linear and stationary data)**

Benefits

Easy implementation:

- **Easy and inexpensive to implement in software or hardware**

Real-time operation:

- **Operates and yields physically meaningful results in real time**

Market Potential
Benefits

Multifunctionality:

- Generates IMFs through an adaptive algorithm from a data set with which other methods fail

- Examines previously unattainable results for aiding diagnosis

- Provides new, quantitative measurements that enhance understanding of underlying physiological phenomena
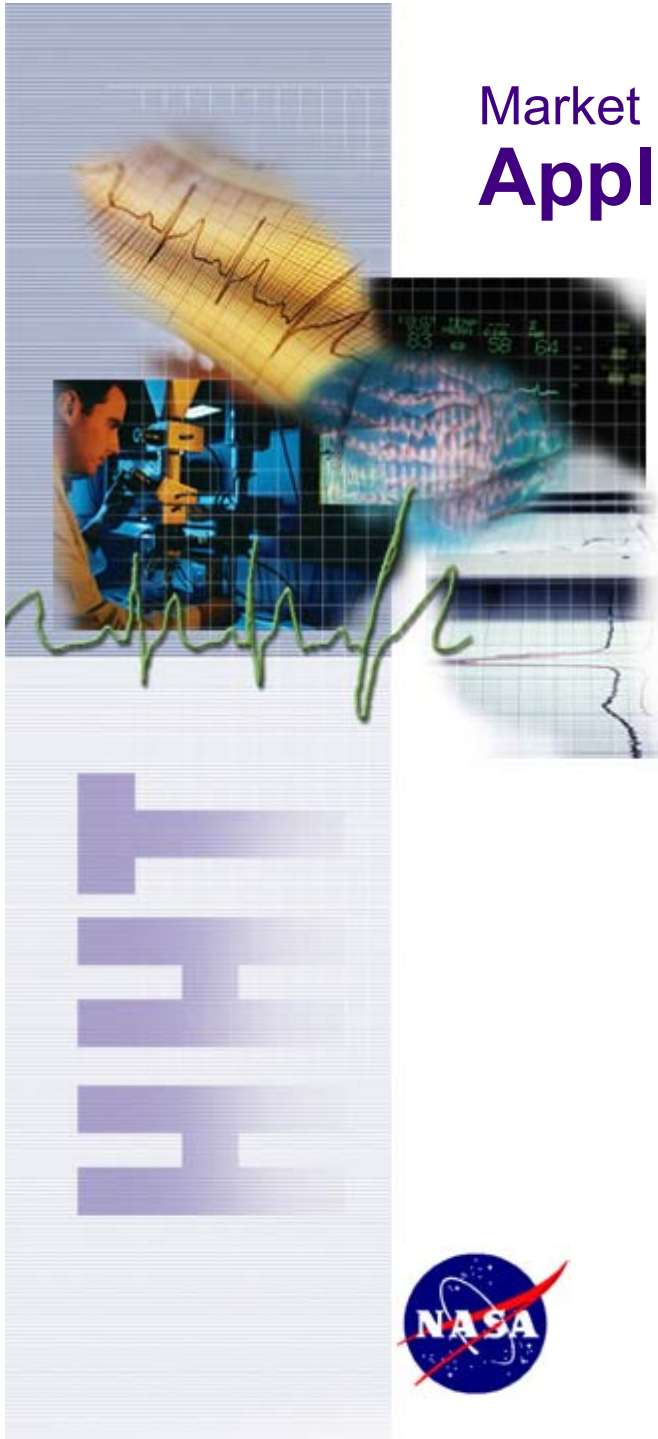
Applications

NASA:

- **Analyzing and correcting satellite data**
- **Analyzing data to understand underlying phenomena**
- **Fusing data from multi-sensors**

Other government entities:

- **DOT (seismic load and nondestructive testing)**
- **FBI (speech analysis and speaker identification)**
- **U.S. Navy (shock loading and nondestructive testing)**
- **NIST (machine health monitoring)**

Applications

Commercial:

- **Predicting incipient failure of machinery**

- **Analyzing sound waves, electromagnetic waves, heat conduction/convection, and mechanical vibrations**
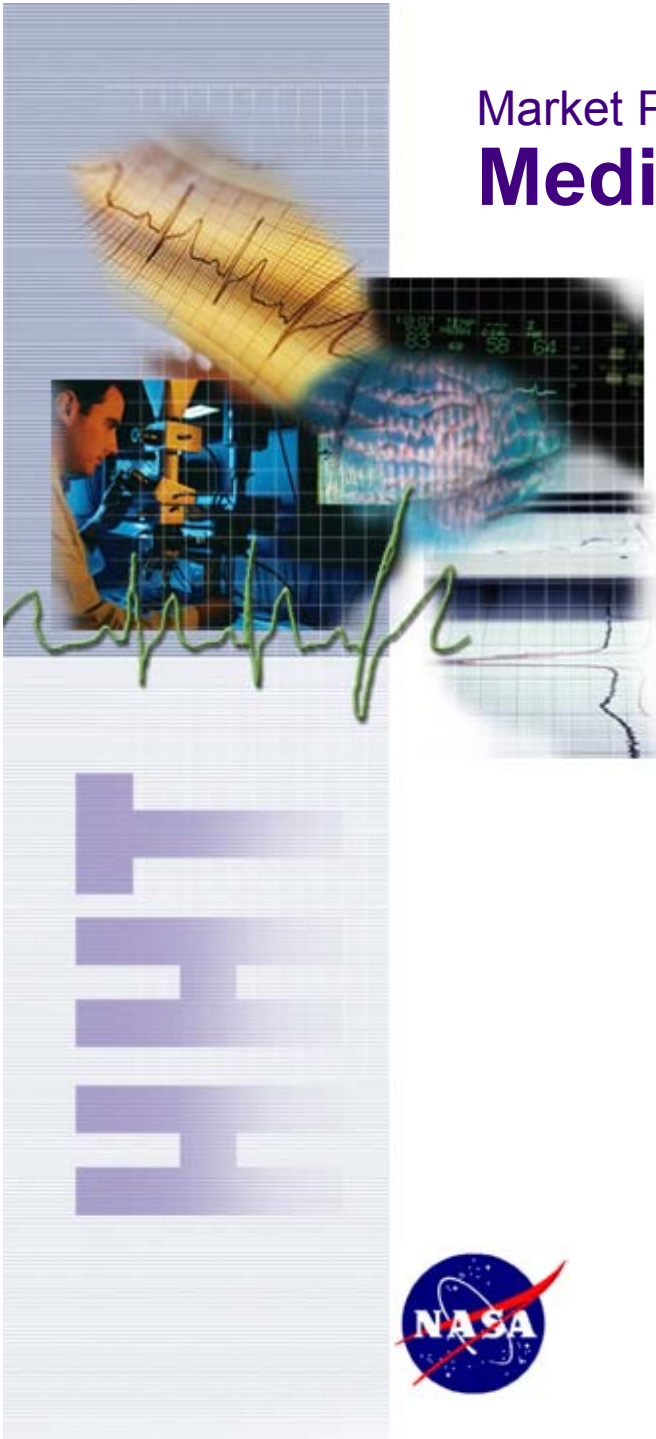
- **Interpreting nonstationary signals**

Medical

Medical Applications

Analysis of acoustic, biological, and physiological signals:

- Blood pressure

- Heart pulse interval

- Heart rate

- Plethysmogram signals

- Electroencephalogram (EEG) signals

- Temperature signals

- Blood oxygen levels

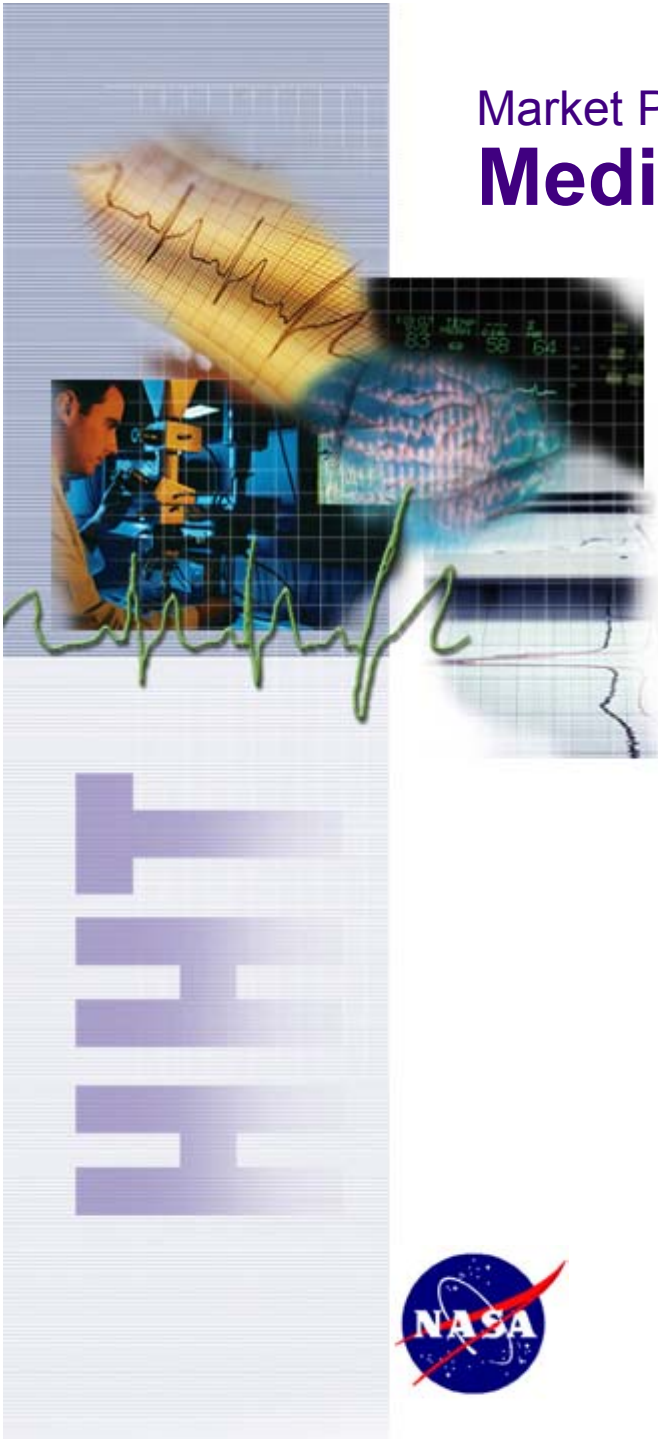- Speech (i.e., soundwaves)

- Electrocardiogram (ECG)

Medical Applications

Noise filtering:

- Reducing noise

- Increasing signal clarity

Research:

- Studying the effect of one variable on another to get a deeper understanding of the underlying physiological phenomenon

Medical Applications

Diagnosis of an abnormal condition or disease:

- Sleep apnea

- Neurological disorders (e.g., epilepsy and Parkinson's disease)

In vitro studies:

- Current flow across membranes (i.e., patch clamping)

- Fluorescence in confocal microscopy

- Analysis of spectroscopic signals

Medical Applications

Identification of outliers:

- **Heart rate**

- **Blood pressure**

- **Other physiological functions**

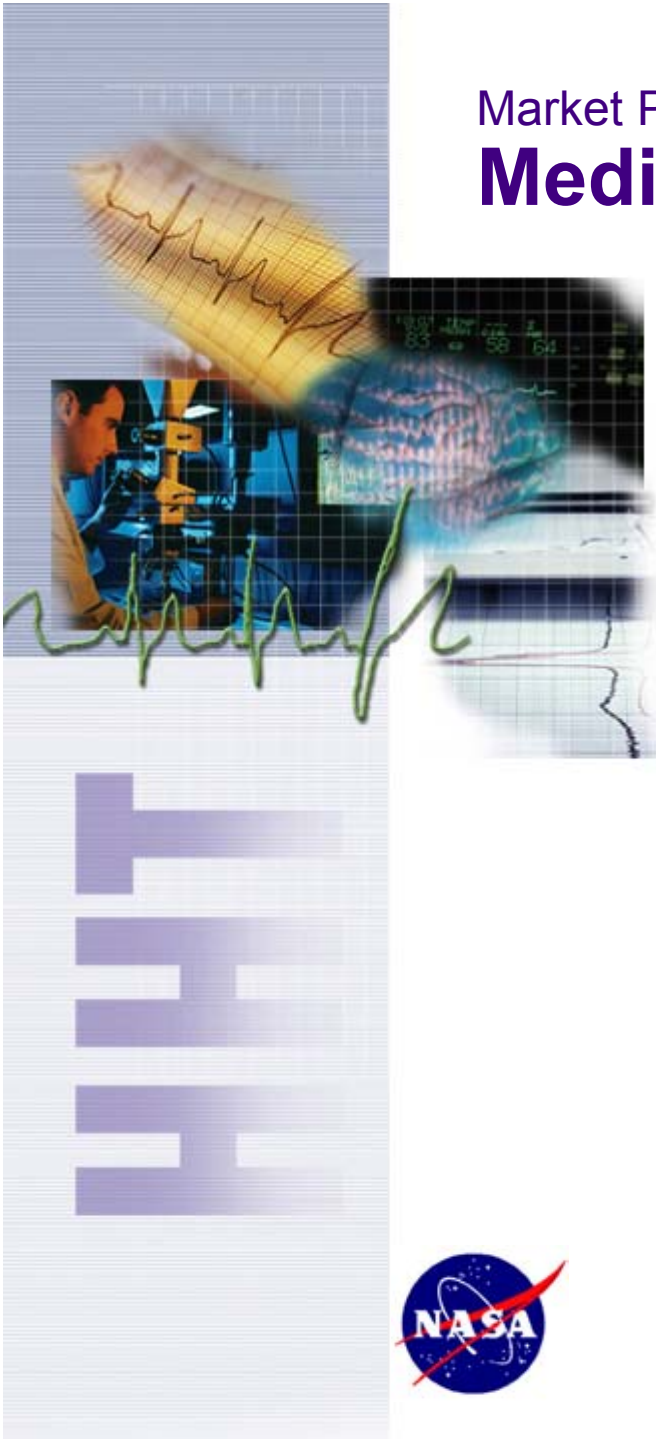## Deriving an analytical function representative of a biological phenomenon
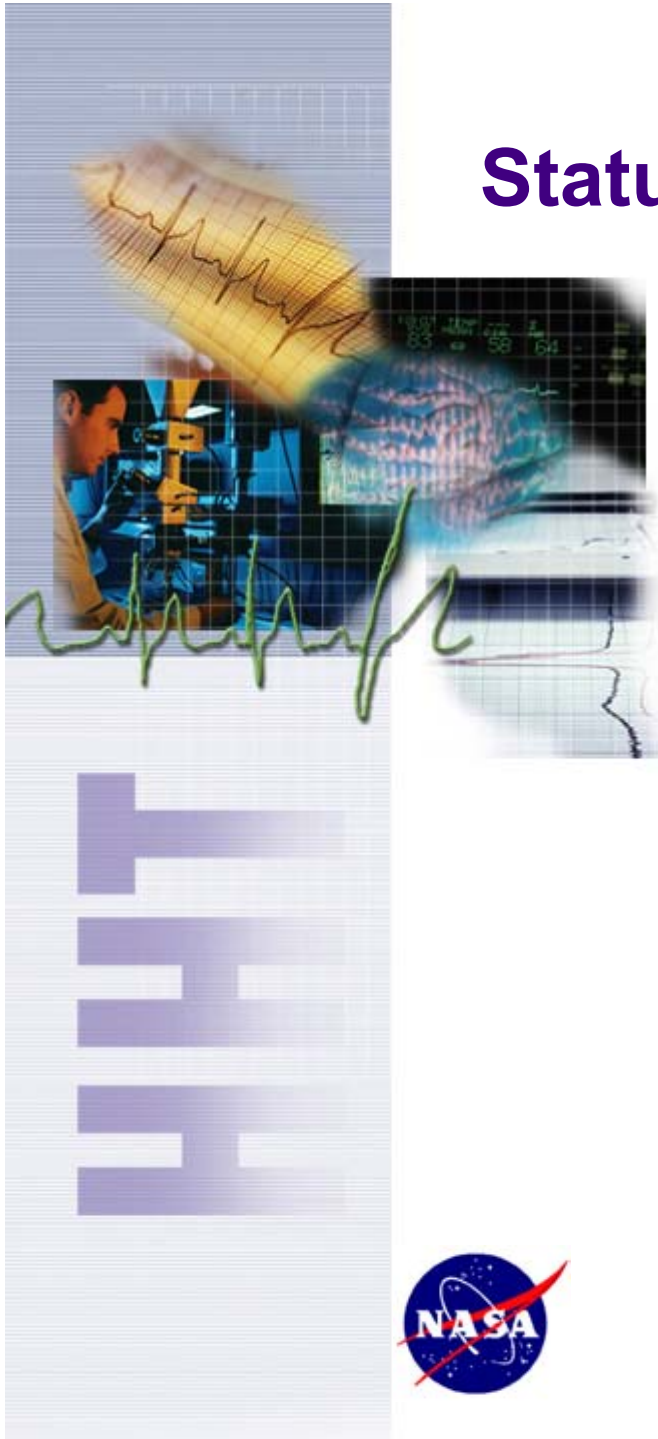
Medical Applications

Drug discovery:

- **Assessing protein structure**

- **Examining protein-protein interactions**

Tissue engineering and design

Status of Development

- **Implemented and tested in the following medical applications:**
  - » **Blood pressure data from the pulmonary artery of a rat**
  - » **Pulmonary blood pressure signals in response to step changes in oxygen concentration in the breathing gas**
  - » **Heart pulse interval comparing sleep apnea condition to a non-apnea condition**
  - » **Epileptic seizure heart pulse data**

- **Figures summarizing results can be found in U.S. Patent 6,381,559**

- **Data and additional results are proprietary and confidential**

Intellectual Property Protection

Issued patents:

- **U.S. Patent No. 6,311,130 Computer Implemented Empirical Mode Decomposition Method, Apparatus, and Article of Manufacture Utilizing Curvature (issued 10/01)**

- **U.S. Patent No. 5,983,162 Computer Implemented Empirical Mode Decomposition Method, Apparatus, and Article of Manufacture (issued 9/99)**

Copyright:

- **Computer Implemented Empirical Mode Decomposition Method, Apparatus, and Article of Manufacture**

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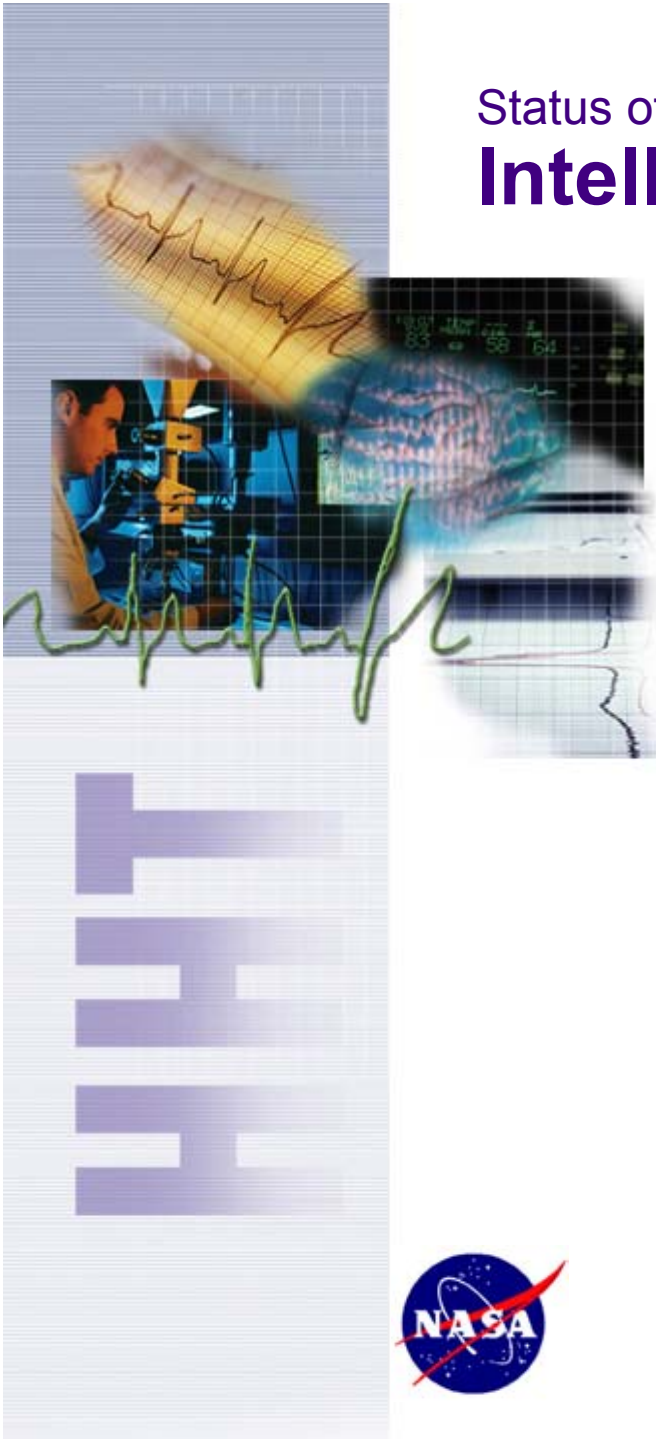
Intellectual Property Protection

Pending patents:

- **U.S. App. No. 09/082,523 Extrema Continuation in Part Allowed (filed 5/98)**

- **U.S. App. No. 09/282,424 Implemented Empirical Mode Decomposition Method, Apparatus, and Article of Manufacture for Analyzing Biological Signals and Performing Curve Fitting (filed 3/99)**

Intellectual Property Protection

Pending patents: (cont)

- **U.S. App. No. 09/729,138
Three Dimensional Empirical Mode
Decomposition Analysis Apparatus and
Method (filed 11/00, inventor Per
Gloersen)**

- **U.S. App. No. 10/073,957
Application of HHT for Acoustical Signal
Analysis: With Special Emphasis on
Speech Analysis, Synthesis,
Identification, Enhancement, and
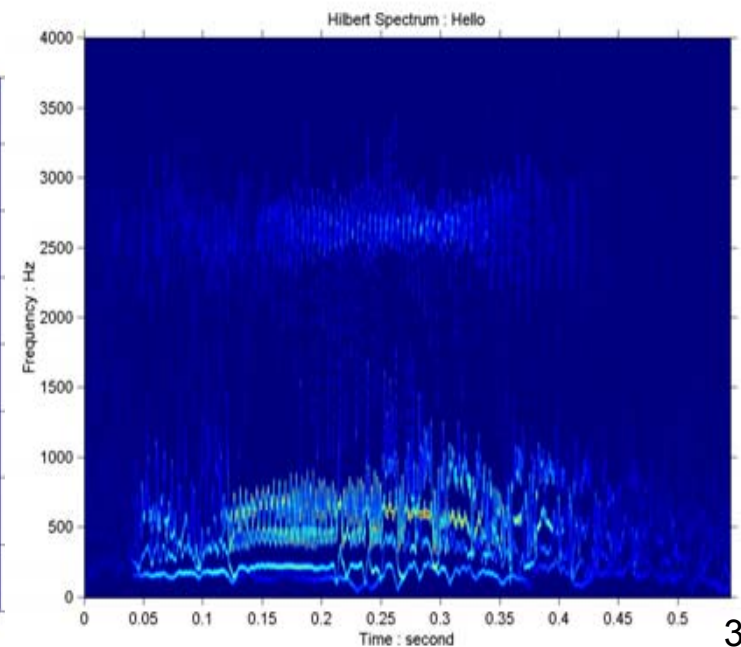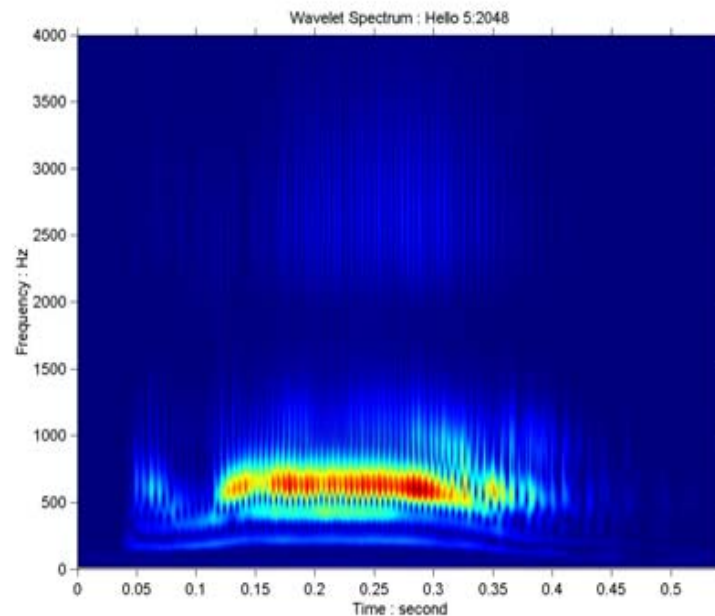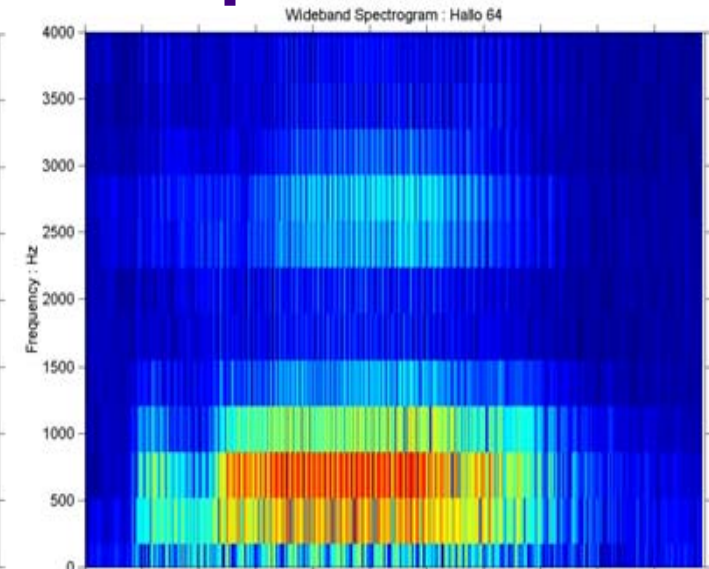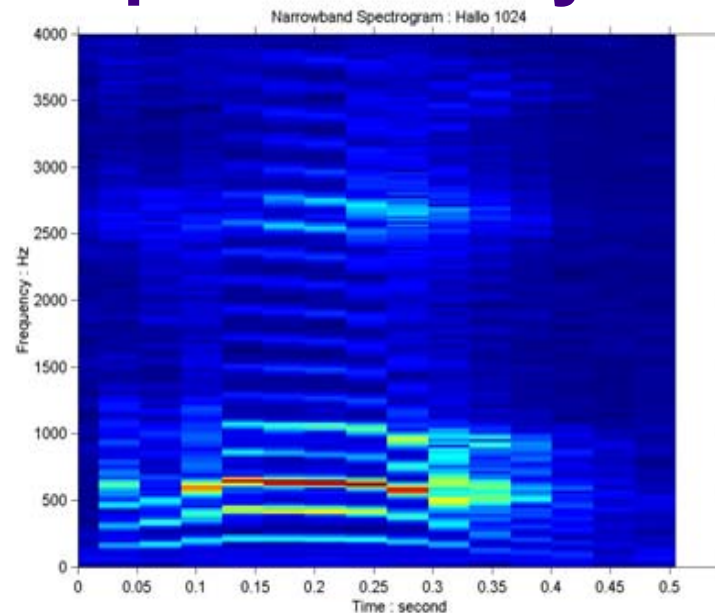Machine Health Monitoring (filed 2/02)**

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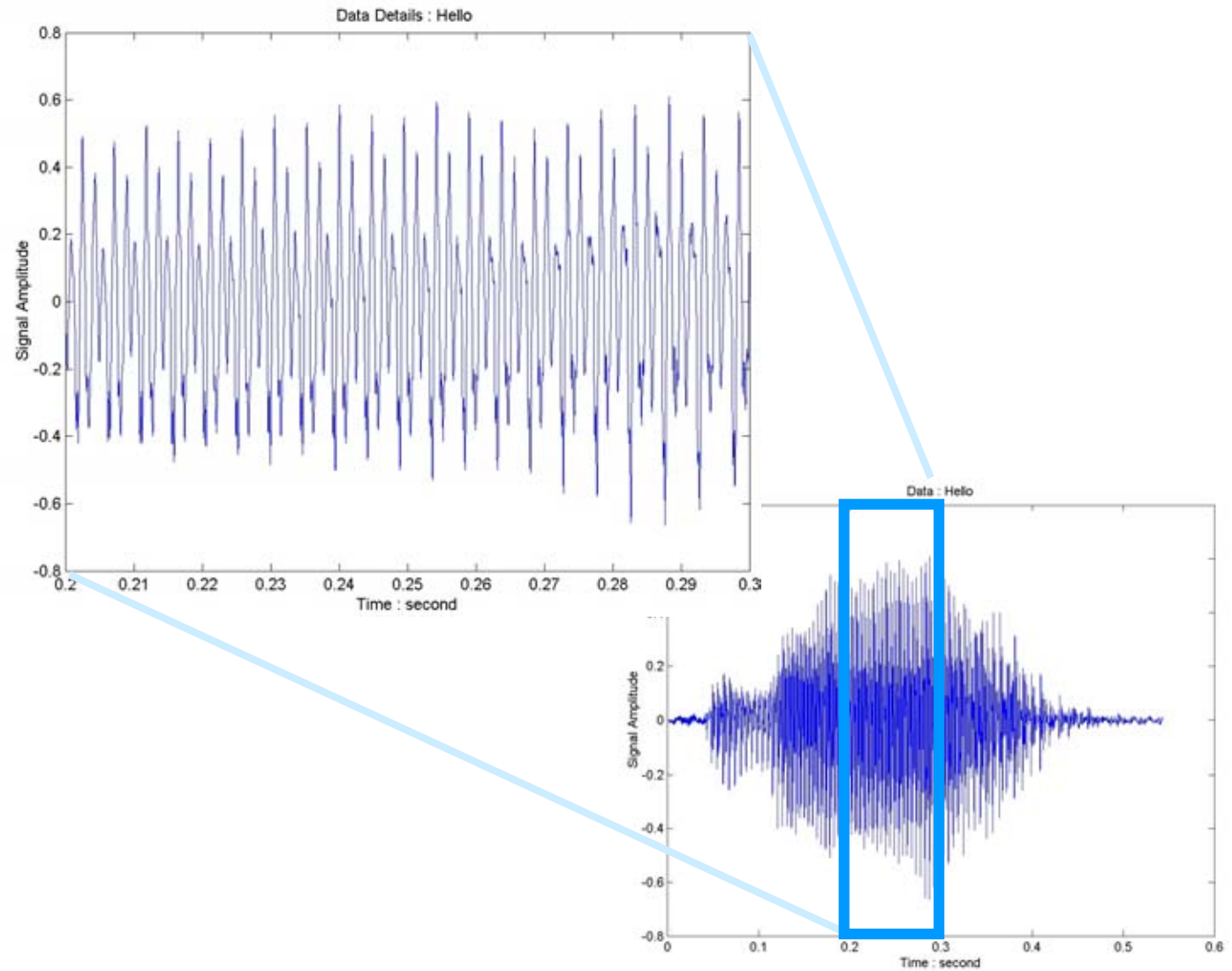
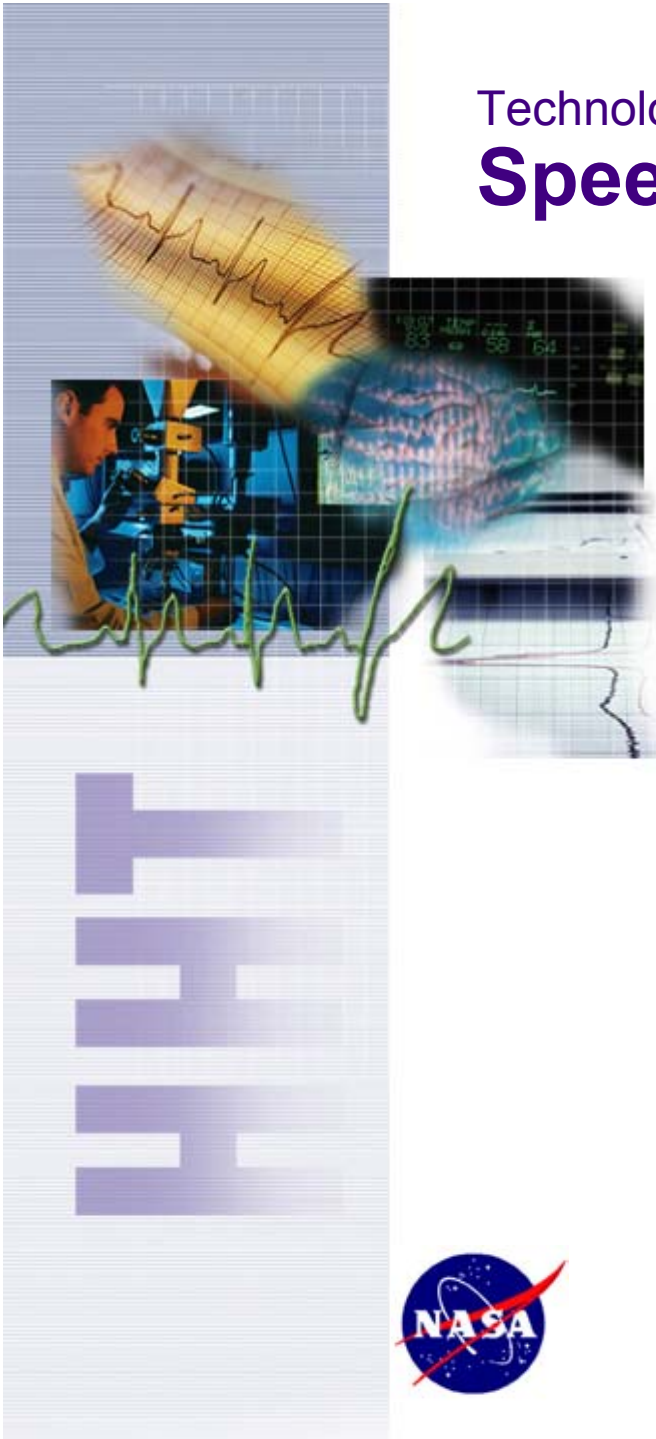# Speech Analysis Example

Speech Analysis Example

Speech Analysis Example

Benefits in sound enhancement:

- **Fourier filter is linear and stationary; it works in frequency domain**

- **Fourier filter takes away harmonics and dulls sharp corners of all fundamentals**

- **EMD filter is nonlinear and intermittent; it works in time domain**

- **EMD filter removes unwanted noise of short periods and leaves fundamentals unchanged**

Ongoing Work

Sponsored research, via Space Act Agreements:

- **Universities**

- **Government laboratories**

Conferences:

- **SIAM (Society for Industrial and Applied Mathematics) and CAIMS (Canadian Applied and Industrial Mathematics Society) Joint Annual Meeting, 2003; Montreal Canada**

- **First International Symposium on HHT Developments and Applications, 2003; Taipei, Taiwan**

Summary

- **Licensing and partnering opportunity**

- **Enabling technology with significant commercial potential in medicine**

- **Significant benefits**

  » **Precision, flexibility, accuracy, easy implementation, real-time operation, and multifunctionality**

Summary

- **Numerous application possibilities**

  » **Extracting intrinsic mode functions, aiding in diagnosis, gaining understanding of physiological phenomena**

- **Intellectual property protected**

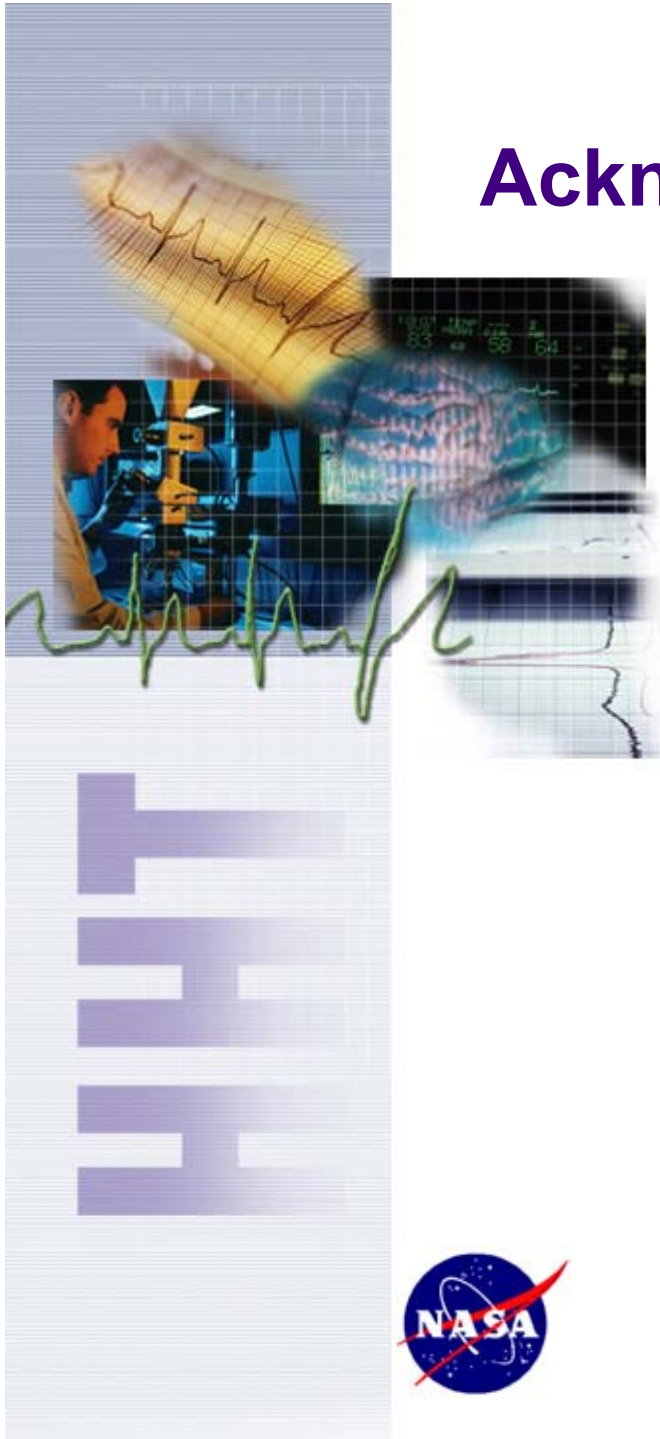- **Concepts demonstrated in medical applications**

Contact Info

For more information, please contact:

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Acknowledgements

- **Inventor Norden Huang**

- **Member of National Academy of Engineering**

- **Presentations made at numerous universities and other NASA field centers**

- **Papers published**

  » **Proceedings of the Royal Society of London**

  » **Proceedings of the National Academy of Sciences**

  » **Annual Review of Fluid Mechanics**

  » **Bulletin of Seismological Society of America**

Acknowledgements

- **Awards**

  » **NASA Exceptional Space Act, 1998**

  » **Federal Government Technology Leadership Award, 1999**

  » **Federal Laboratory Consortium Technology Development Award, 2001**

  » **R&D 100 Award, 2001**